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Procedia Environmental Sciences 10 (2011) 589 – 594

**Procedia**

Environmental Sciences

2011 3rd International Conference on Environmental  
Science and Information Application Technology (ESIAT 2011)

# The Improvement of DTC System Performance on Fuzzy Control

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## Abstract

The large torque ripples exist in induction motors based on conventional direct torque control (DTC) system, especially at a low speed. For the problem of DTC, fuzzy control theory is applied to DTC system. Based on fuzzy control of induction motor direct torque control system model is constructed in this paper. Fuzzy controller in the system selects the voltage space vector. The control system is simulated on the platform of Matlab/simulink. The results of the simulation prove that the method of the fuzzy DTC controller can effectively improve the low-speed performance of the induction motor, reduce the torque ripple, and have a good dynamic response performance.

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Selection and/or peer-review under responsibility of Conference ESIAT2011 Organization Committee.

*Keywords:* Direct Torque Control (DTC) system; Voltage space vector; Fuzzy control; Simulation

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## 1. Introduction

Asynchronous motor is a higher-order, multivariable, strongly coupled nonlinear system. Induction motor direct torque control system is a high dynamic performance AC motor VVVF (Variable Voltage and Variable Frequency) speed control system. It is the second developed after vector control system [1]. Induction motor direct torque control system has the characteristic of fast torque response[2-4]. It is an ideal induction motor drive system. However, the large torque ripples exist in induction motors based on conventional DTC system, especially at a low speed. For the problem, in recent years some scholars have proposed improved method. A new speed control strategy combining sliding mode theory and direct torque control was designed in Ref. [5]. The article mainly deals with those key problems associated with conventional direct torque control of permanent magnet synchronous motor, such as large torque ripple speed overshooting and poor anti-disturbance ability. The low-pass filter for magnetic flux of induction motor stator has been designed based on a voltage model of low speed in Ref. [6]. In order to optimize the Performance of Direct Torque Control system, a novel controller-IP speed regulator was used in Ref. [7].

In this paper, fuzzy control theory is applied to DTC system. Using MATLAB / SIMULINK platform, based on fuzzy control of induction motor direct torque control system simulation model is constructed. Through the simulation model, the dynamic performance and static control performance are studied.

## 2. Structure of DTC System Based on Fuzzy Control

DTC system occupies an increasingly important position in the modern AC electric drive. This section describes structure and principle of the DTC system based on fuzzy control.

### 2.1. Basic principles

Motor electromagnetic torque is the stator flux and rotor flux interaction. It is showed in equation (1).

$$T_e = K_T |\vec{\psi}_s| |\vec{\psi}_r| \sin \theta \quad (1)$$

$\vec{\psi}_s$  is the stator flux space vector.  $\vec{\psi}_r$  is the rotor flux space vector.  $\theta$  is the angle between the stator flux and the rotor flux. It is called the flux angle.  $K_T$  is the torque coefficient. In actual operation, the stator flux space vector amplitude is usually kept constant in order to take full advantage of core. The amplitude of rotor flux space vector is determined by the load. So by changing the flux angle can change the size of the electromagnetic torque.

Fuzzy control is the expert knowledge and experience in field operations personnel as knowledge base. It is converted into operation through specific fuzzy rules and fuzzy reasoning rule.

Fuzzy control uses expert's knowledge and operators' experience to form knowledge-base, which is changed into reasoning algorithms by particular fuzzy rules. Output is given by fuzzy control system, which includes fuzziness of input, reasoning algorithms and defuzzification. Fuzzy control employs fuzzy math and expert's control experience to construct fuzzy controller without building precise math model of object. Thus, fuzzy control can not affected by uncertainty, inaccuracy, and noise meter nonlinear and time-variability.

### 2.2. Structure of DTC system based on fuzzy control

Fig. 1 shows the simulation model of DTC system based on fuzzy control.

In the simulation model, asynchronous motor module is according to the voltage equation, flux equation, torque equation and the equation of motion of induction motor. The module has four inputs  $\{U_A \ U_B \ U_C \ T_L\}$  and eight outputs  $\{\psi_{s\alpha} \ \psi_{s\beta} \ \psi_{r\alpha} \ \psi_{r\beta} \ i_{s\alpha} \ i_{s\beta} \ T_e \ n\}$ . Because the module's output has included the stator fluxes  $\{\psi_{s\alpha} \ \psi_{s\beta}\}$  and torque  $\{T_e\}$ , so flux and torque estimation model is not required. Structure of the system becomes simple.

In the asynchronous motor direct torque control system, according to the different angle of stator flux vector space, the stator flux locus is divided into twelve different sectors. In the simulation model, the sector signal selection module is written by the M S-function implementation, the sector select signal  $\{\theta\}$  is an integer from 1 to 12. Feedback value of the stator flux vector magnitude minus the flux reference and then the flux error signal  $\{\Delta\psi_s\}$  is received. The signal by subtracting between the speed reference value and speed feedback value is transformed into the torque reference through the proportional regulator. The torque reference minus the feedback signal torque and then the torque error signal  $\{\Delta T_e\}$  is obtained.

In the conventional direct torque control system, the flux error and the torque error pass through the hysteresis comparator to compare. According to stator flux trajectory in which the sector, the inverter switch control signal is given. This is called the bang-bang control. By this control, you can get a faster dynamic response, but the torque ripple and speed range is limited, especially in low speed the

performance is significantly bad. The fuzzy controller can put the flux error signal  $\{\Delta\psi_s\}$  and torque error signal  $\{\Delta T_e\}$  into fuzzy linguistic variables  $\{E_{\psi_s}, E_{T_e}\}$ . Three language values fuzzy subsets  $\{N, ZO, P\}$  is defined in the variable universe and five language values fuzzy subsets  $\{NL, NS, ZO, PS, PL\}$  is defined in the variable universe. Membership functions of fuzzy subsets are shown in Fig.2 and Fig.3.

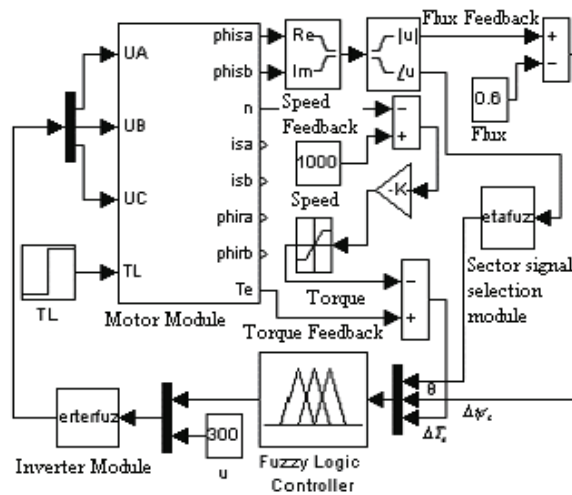


Fig. 1. simulation model of DTC system based on fuzzy control

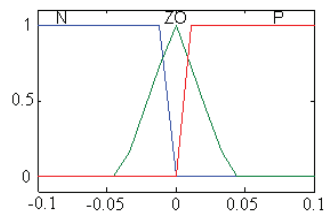


Fig. 2. curve of membership degree function of  $E_{\psi_s}$

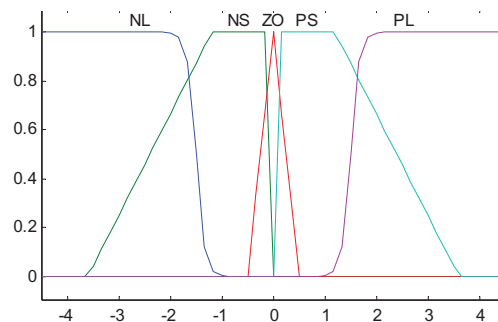


Fig. 3. curve of membership degree function of  $E_{T_e}$

Meanwhile, the sector select signals  $\theta$  are discrete values, twelve of fuzzy sets  $\theta_1 \sim \theta_{12}$  are defined in its domain. Its membership function is shown in Figure 4. At this point, the output of fuzzy controller is the control variable of the inverter switch state. Its values are integer discrete 0-7. It can be single-valued fuzzy sets and rod membership functions.

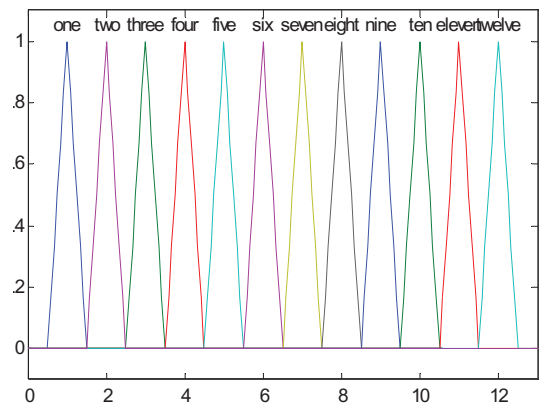


Fig. 4. Curve of membership degree function of  $\theta$

In order to address the shortcomings of bang-bang control, speed up the torque response, while minimizing torque ripple and increasing the speed range are necessary. Direct torque control requirements the trajectory of stator flux similar to circle. In accordance with the requirements can be determined as shown in Table 1, 180 control rules to select the most appropriate voltage space vector that is, the inverter switching state.

Table 1. Rules of fuzzy controller

$E_{\psi_s}$	$E_{T_e}$	$\theta_1$	$\theta_2$	$\theta_3$	$\theta_4$	$\theta_5$	$\theta_6$	$\theta_7$	$\theta_8$	$\theta_9$	$\theta_{10}$	$\theta_{11}$	$\theta_{12}$
N	NL	6	2	2	3	3	1	1	5	5	4	4	6
	NS	6	6	2	2	3	3	1	1	5	5	4	4
	Z	7	7	0	0	7	7	0	0	7	7	0	0
	PS	4	7	6	0	2	7	3	0	1	7	5	0
	PL	5	4	4	6	6	2	2	3	3	1	1	5
ZO	NL	6	2	2	3	3	1	1	5	5	4	4	6
	NS	6	6	2	2	3	3	1	1	5	5	4	4
	Z	7	7	0	0	7	7	0	0	7	7	0	0
	PS	7	7	0	0	7	7	0	0	7	7	0	0
	PL	5	4	4	6	6	2	2	3	3	1	1	5
P	NL	3	3	1	1	5	5	4	4	6	6	2	2
	NS	2	3	3	1	1	5	5	4	4	6	6	2
	Z	0	7	7	0	0	7	7	0	0	7	7	0
	PS	0	7	7	0	0	7	7	0	0	7	7	0
	PL	1	5	5	4	4	6	6	2	2	3	3	1

IF ( $\theta$  is  $A_i$ ) and ( $E_{\psi_s}$  is  $B_i$ ) and ( $E_{T_e}$  is  $C_i$ ) then (n is  $N_i$ )

Where,  $A_i$   $B_i$   $C_i$   $N_i$  is a language-valued fuzzy sets of  $\theta$   $E_{\psi_s}$   $E_{T_e}$   $n$ . MAMDANI algorithm is used for fuzzy reasoning. Accordance with the above control rules and fuzzy reasoning method with maximum degree can be a clear definition of the calculated amount of control in order to select the most appropriate voltage space vector. In addition, the Inverter module of the simulation model is implemented by the M S-function. It makes the DC voltage source input reverse into three-phase AC voltage input.

### 3. System Simulation

In order to verify the correctness of the simulation model and the effect of fuzzy control rules, the following simulation experiment was done.

Induction motor parameter is set to: moment of inertia  $J = 0.125 \text{ kg} \cdot \text{m}^2$ , the stator inductance  $L_s = 94 \text{ mH}$ , rotor inductance  $L_r = 88 \text{ mH}$ , stator and rotor mutual inductance  $L_m = 82 \text{ mH}$ , stator resistance  $R_s = 0.95 \Omega$ , rotor resistance  $R_r = 1.82 \Omega$ , the number of pole pairs  $n_p = 2$ .

Given parameter is set to: given speed  $n_g = 1000 \text{ rpm}$ , given flux  $\psi_g = 0.6 \text{ Wb}$ , the DC voltage  $U = 300 \text{ V}$ .

Simulated motor works as follows: starting, the motor load torque is  $10 \text{ N} \cdot \text{m}$ , after the load torque dumps to  $6 \text{ N} \cdot \text{m}$ .

Speed response of the simulated waveform is shown in Fig. 5. The motor rapid starts in maximum torque, when the time is 5s the motor speed becomes stable, and almost no overshoot. When the time is 10s the load dumps, after a short dynamic process, the speed becomes stable again. Because the proportional control is used in the simulation model, a difference exists between the actual speed and the given speed.

Electromagnetic torque response simulation waveform is shown in Fig. 6. Electromagnetic torque slight fluctuations around the load torque when the load torque is stable. Electromagnetic torque quickly tracks the changes in load torque when the loads torque sudden changes. Torque response of the system is stable, fast and accurate.

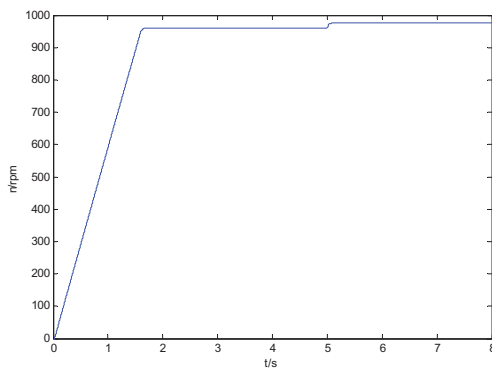


Fig. 5. Response of  $n$

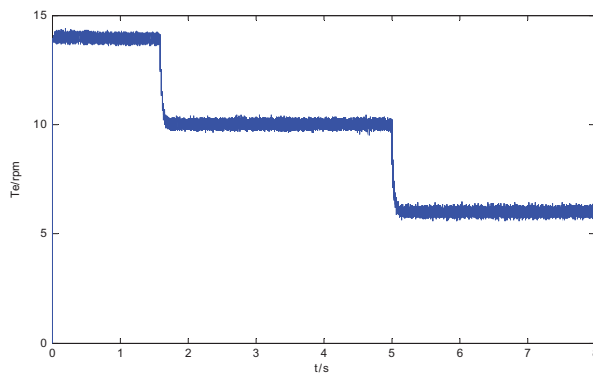


Fig. 6. Response of  $T_e$

Stator flux trajectory simulation waveforms are shown in Fig. 7. Among them, Fig. 7 (a) is the stator flux trajectory of the conventional direct torque control system; Fig. 7 (b) is the stator flux trajectory of the fuzzy direct torque control system.

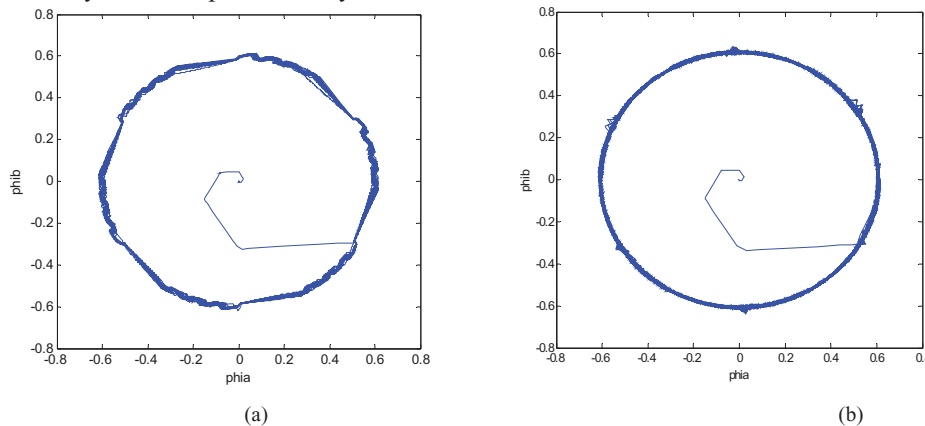


Fig. 7. Simulation waveforms of the stator flux trajectory (a) the stator flux trajectory of the conventional DTC system; (b) the stator flux trajectory of the fuzzy DTC system

#### 4. Conclusion

Fuzzy controller was instead of the torque and stator flux hysteresis controller in the traditional direct torque control algorithm. Fuzzy direct torque control system controller processes the flux selection signal, the torque select signal and the sector select signal; the most appropriate voltage space vector can be getting to control the inverter switching state. Fuzzy control system and the traditional bang-bang control compared. Since the stator flux trajectory is closer to circular, so torque response is faster and torque ripple is smaller. It has greatly improved the dynamic and the static of the direct torque control system, increased the robustness of direct torque control system.

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